https://doi.org/10.37815/rte.v37n1.1343
Original articles

Effective Strategies for Mitigating Voltage and Frequency Fluctuations in Isolated Microgrids: A Literature Review

Estrategias efectivas para mitigar fluctuaciones de tensión y frecuencia en microrredes aisladas: Una revisión de literatura

Santiago Arcos-Echeverría[1] https://orcid.org/0009-0001-3133-2257,
Danny Ochoa-Correa[2] https://orcid.org/0000-0001-5633-1480

[1]*Universidad de Cuenca, Facultad de Ingeniería* , Cuenca, Ecuador
santiago.arcos@ucuenca.edu.ec

[2]*Universidad de Cuenca, Facultad de Ingeniería, Departamento de Ingeniería Eléctrica, Electrónica y Telecomunicaciones*, Cuenca, Ecuador
danny.ochoac@ucuenca.edu.ec

Sent: 2025/06/22
Accepted: 2025/10/29
Published: 2025/12/15

Abstract

Territorial expansion has posed new challenges for electrical systems, driving the need to electrify remote rural areas and island territories. This demand has fostered the development of electrical microgrids based on distributed renewable generation, which, due to their low inertia, experience voltage and frequency instability—particularly during overloads or transitions between isolated and grid-connected modes. This article presents a literature review focusing on strategies to mitigate these fluctuations, analyzing 28 recent publications. The findings highlight adaptive controllers, smart inverter compensation, and the integration of energy storage systems as dynamic support tools, showing a preference for solutions based on power electronics and predictive control algorithms.

Keywords: renewable energy, energy storage systems, voltage fluctuations, frequency fluctuations, low-inertia systems.

Summary: Introduction, Methodology, Descriptive Analysis of Literature, Isolated Microgrids, Control Strategies for the Stability of Isolated Microgrids, Conclusions.

How to cite: Arcos-Echeverría, S. & Ochoa-Correa, D. (2025). Effective Strategies for Mitigating Voltage and Frequency Fluctuations in Isolated Microgrids: A Literature Review. *Revista Tecnológica - Espol, 37(2), 145-169.* https://rte.espol.edu.ec/index.php/tecnologica/article/view/1343

Resumen

La expansión territorial ha generado nuevos desafíos para los sistemas eléctricos, impulsando la necesidad de electrificar zonas rurales de difícil acceso y territorios insulares. Esta demanda ha fomentado el desarrollo de microrredes eléctricas basadas en generación distribuida a partir de fuentes renovables, las cuales, debido a su baja inercia, presentan inestabilidad en frecuencia y voltaje, especialmente durante sobrecargas o transiciones entre modos de operación aislado y conectado a red. Este artículo presenta una revisión de literatura sobre estrategias para mitigar estas fluctuaciones, analizando 28 publicaciones recientes. Entre los enfoques identificados se destacan los controladores adaptativos, la compensación mediante inversores inteligentes, y la incorporación de almacenamiento energético como mecanismo de soporte dinámico, evidenciándose una preferencia por soluciones basadas en electrónica de potencia y algoritmos predictivos.

Palabras clave: energía renovable, sistemas de almacenamiento de energía, fluctuaciones de tensión, fluctuaciones de frecuencia, sistemas de baja inercia.

Introduction

Implementing electrical microgrids in modern power systems is essential as societies transition toward more sustainable and resilient energy infrastructures. Isolated microgrids, which operate independently or in conjunction with the main grid, face the critical challenge of managing voltage fluctuations. The increasing integration of intermittent renewable energies, such as solar and wind power, and the concurrent abandonment of traditional fossil fuels exacerbate this challenge. The need for a robust solution is evident, as these fluctuations can lead to inefficiencies and disruptions in power supply, affecting the reliability of the entire power grid (Pilehvar & Mirafzal, 2020a). In contrast, microgrids connected to the public grid can dynamically control the voltage at the alternating current (AC) node to maintain stability. To address fluctuations in isolated microgrids, most solutions in the literature modify the conventional inverter control scheme using various techniques to mitigate short-term transients and prevent outages caused by random events.

For example, in the context of blackouts, Bassey and Butler-Purry (2022) use the mixed-integer linear programming (MILP) method to implement black start, restoring the system as quickly as possible. However, authors Bassey and Butler-Purry (Bassey & Butler-Purry, 2020) indicate that the MILP method fails to compensate for load balance and requires higher computational capacity due to its analysis in an isolated microgrid adapted from the IEEE 13-node test feeder.

To address frequency fluctuations in photovoltaic units, Pilehvar and Mirafzal (2020c) propose using an adaptive piecewise droop (APD) curve in inverters. In another study, the same authors (Pilehvar & Mirafzal, 2020a) employ a piecewise linear-elliptic (PLE) drop in energy storage systems to improve inverter stability and reduce voltage variations through reactive energy injection/absorption during transients.

Furthermore, energy storage systems used in renewable energy-based electrical systems, such as wind and solar, play a crucial role in storing excess electricity and providing system stability (Ochoa & Martinez, 2021).

Another approach, the virtual synchronous generator, has been shown to enhance the inertia and damping of inverter-based distributed generators, thereby improving frequency regulation in isolated microgrids (Yuan et al., 2018).

A strategy called 3P four-leg inverters (3P4LI) has also been proposed by Mohamed Salim and El-Sayed Salem Aboraya (Mohamed Salim & El-Sayed Salem Aboraya, 2024). This strategy is based on connecting DG to improve stability by employing a new control architecture called triple loop compensation (TLC), which integrates PI, PR, and feedforward schemes. This is achieved by optimizing the TLC parameters (Mohamed Salim & El-Sayed Salem Aboraya, 2024).

There are also methods based on distributed generators, such as the one proposed by A. R. Singh et al. (2023), which minimize voltage unbalance using a positive-sequence controller and a negative-sequence controller, yielding favourable results even in the presence of time-varying loads.

Another method analyzed involves implementing a frequency controller, which utilizes the load's sensitivity to operating voltages to achieve load regulation (Kokila Vani et al., 2021). This method eliminates the need for additional communication infrastructure by relying solely on local frequency and voltage for feedback.

For the same purpose, an adaptive switched filter compensator (ASFC) with a PID controller has been proposed by Elmetwaly et al. (2020) to improve the dynamic performance of the microgrid. The Grasshopper Optimization Algorithm (GOA) has been applied to this controller to allow it to adapt and self-tune according to changes in system conditions.

Given the increasing deployment of renewable-based microgrids in remote, rural, and islanded areas, ensuring stable and reliable operation has become a critical engineering challenge. These systems often rely on inverter-based distributed generation with low or virtually no mechanical inertia, making them inherently more susceptible to voltage and frequency instabilities—particularly during load transients, mode transitions, or fault conditions. While numerous studies have proposed isolated solutions to mitigate these issues, the rapid proliferation of control strategies, coupled with the lack of standardized evaluation frameworks, has resulted in a fragmented research landscape. Existing reviews tend to focus on specific technologies (e.g., battery energy storage or virtual synchronous generators) or address either voltage or frequency regulation separately, without offering an integrated analysis across multiple approaches.

This literature review addresses that gap by identifying, classifying, and analyzing 28 peer-reviewed studies published between 2017 and 2025 that examine mitigation methods involving smart inverters, energy storage systems, and advanced control algorithms. The findings provide a comprehensive overview of recent technological developments, highlighting trends, advantages, and limitations of current solutions. This offers valuable insights for researchers and practitioners seeking to enhance the dynamic performance of low-inertia electrical systems.

Methodology

The literature review presented in this article follows a structured approach, incorporating elements of the PRISMA methodology for systematic literature reviews (SLR) (PRISMA-P Group et al., 2015). This methodology specifies that the review should have a well-defined methodological framework to ensure a comprehensive explanation of the process, enabling potential replication of the work. To achieve this, we considered the 17 items outlined by Shamseer et al. (2015), which can be categorized into administrative information, introduction, and methods.

Once the context of the research topic was established, the search was conducted in the SCOPUS bibliographic database. Scopus is a preferred database for literature reviews due to its comprehensive coverage of articles from reputable journals across diverse disciplines, including IEEE, MDPI, ScienceDirect, and others. This extensive aggregation ensures inclusive representation of scholarly research, enabling researchers to access diverse perspectives and findings. Additionally, Scopus's commitment to quality control and its global reach make it a reliable source for high-quality, peer-reviewed publications. The database's interdisciplinary content and features, such as citation analysis, further enhance its suitability for researchers seeking a comprehensive and well-rounded understanding of their chosen subject. The Scopus search string used was as follows:

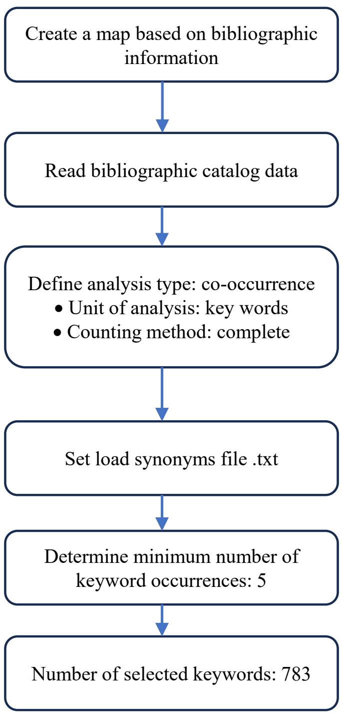
ALL (voltage AND fluctuation AND microgrid AND island) AND PUBYEAR > 2017 AND PUBYEAR < 2026.

The search was conducted on May 25, 2025, and yielded 1641 results in the Scopus database. As shown, the only restriction added to the search string concerned the publication year, focusing on the most recent 8 years (according to the researcher's criteria).

We employed VOSviewer, a powerful bibliometric software, to conduct an in-depth analysis of the identified articles. VOSviewer facilitates the creation and visualization of bibliometric networks derived from journals, research, or other publications. Among its versatile features is the capability to analyse inputted data through term co-occurrence or author recurrence within the chosen subject (*VOSviewer - Visualizing scientific landscapes*, s. f.). This entails exporting metadata in CSV format and subsequently processing it in VOSviewer, following the configuration illustrated in Figure 1.

Figure 1

VOSviewer configuration to create the bibliographic map



This configuration utilizes a synonyms file, meticulously crafted to account for variations in terms that essentially signify the same concept. The specific synonyms considered for this analysis are comprehensively outlined in Table 1.

Table 1

Keywords synonymous for analysis in VOSviewer

Keyword	Replace by
micro grid	microgrid
islanded micro-grid	islanded microgrid
islanded microgrids	islanded microgrid
micro-grid	microgrid
micro-grids	microgrid
microgrid (mg)	microgrid
microgrids (mgs)	microgrids
multi-microgrids	microgrids
small-signal stability	small signal stability
power systems	power system

The acquired outcomes were systematically categorized into clusters and visually represented in a network graph. In this graphical representation, the observer can discern the frequency of occurrence of each keyword relative to the size of its indicator. Furthermore, an analysis of results by publication year allowed for the assessment of the currency of each term. As depicted in Figure 2, terms such as *microgrid, energy storage, energy management, charging, optimization, and electric inverters* exhibited the highest occurrence frequencies. Building on these findings, the next step was to select a term of interest. In this instance, the term "inverter" was chosen, revealing its associations with terms like microgrid and electric inverters, as illustrated in Figure 3.

Figure 2

Cluster chart based on the articles found

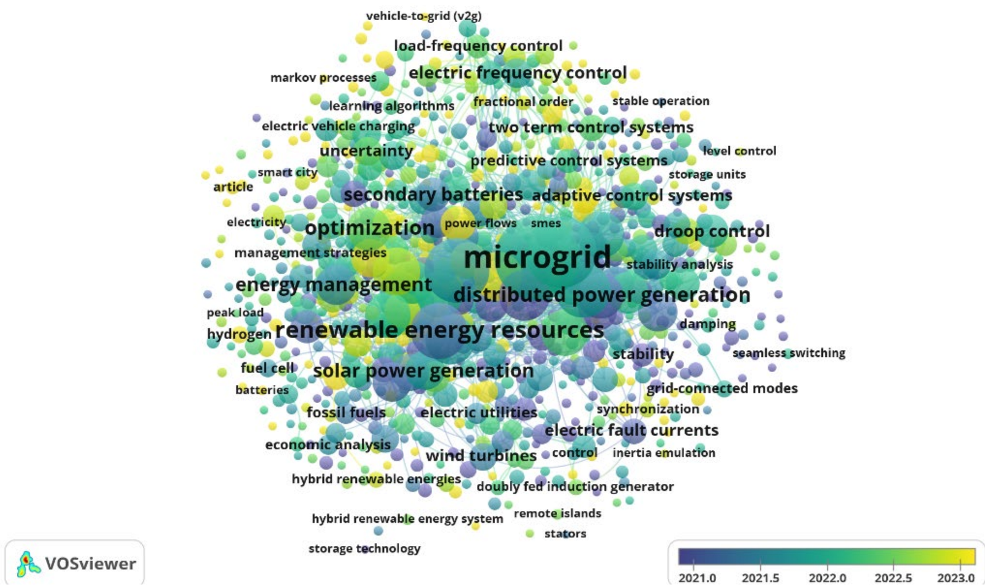
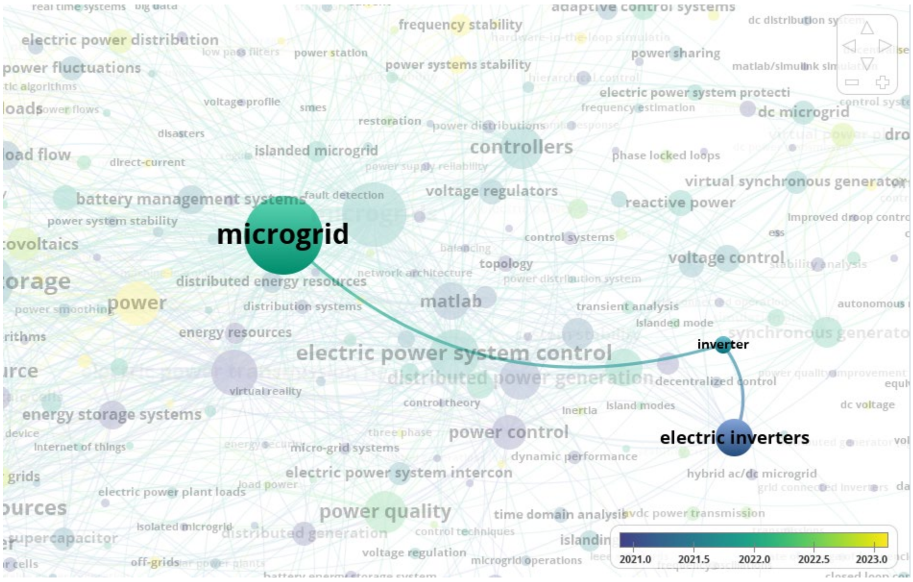


Figure 3

Cluster resulting from the selection of the term inverter



Subsequently, definitive filtering was executed using the terms recommended by VOSviewer, specifically the *inverter microgrid*. This refined curation identified 19 articles directly pertinent to the research topic.

Descriptive Analysis of Literature

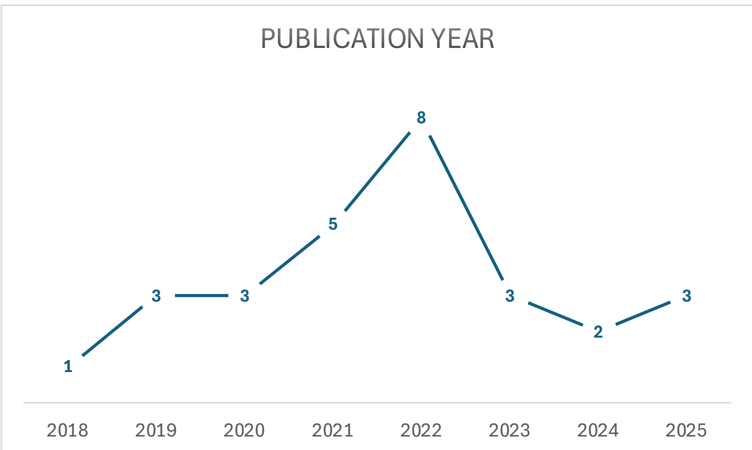
A systematic evaluation of articles was conducted to construct a comprehensive descriptive literature review, encompassing key parameters such as field, year of publication, journal or conference, authors, and language. This multifaceted analysis aimed to provide a nuanced understanding of the literature landscape, facilitating a thorough exploration of trends and contributors.

Publication Year

As indicated earlier, the accepted publication years for this work span from 2018 to 2025. Figure 4 illustrates a discernible trend, highlighting the current and sustained interest in this research topic.

Figure 4

Line diagram by year of publication



Classification by Journal or Conference

Of the 28 analyzed articles, only two publication types were identified: journal articles and conference papers, as shown in Figure 5. However, an in-depth examination of Table 2 reveals no clear preference for any specific journal or conference. Instead, the publications display a relatively even distribution, with most sources contributing only one or, at most, two articles each.

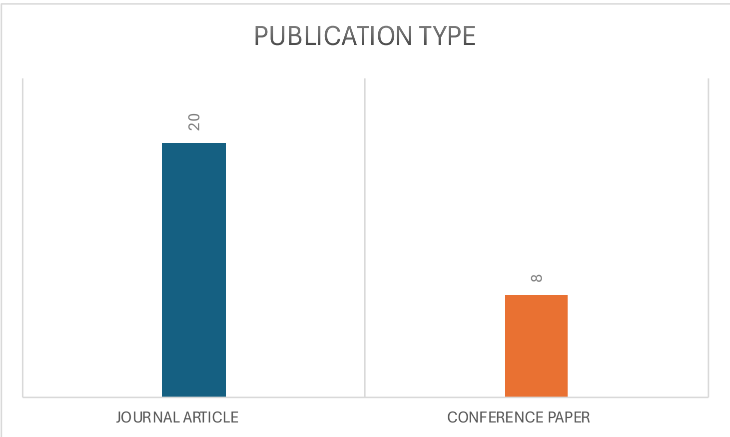
Table 2

Journals or conferences featuring the analyzed articles

Name of the journal or conference	Articles
Appl. Energy	1
Association for Computing Machinery	1
Dianli Xitong Zidonghue/Automation of Electric Power Systems	1
Dianwang Jishu/Power System Technology	1
EEA Electrotec. Electron. Autom.	1
Electr. Power Comp. Syst.	1
Electronics (Switzerland)	1
Energy Reports	1
e-Prime – Advances in Electrical Engineering.	1
Frontiers in Energy Research	1
IEEE Access	1
IEEE Trans Electromagn Compat	1
IEEE Trans Power Electron	1
IEEJ Trans. Electr. Electron. Eng	1
IEEJ Trans. Power Energy	1
Institute of Electrical and Electronics Engineers Inc.	5
Institute of Physics Publishing	1
Iraqi. J. Electr. Electron. Eng.	1
Microelectronics Reliability	1
Springer Science and Business Media Deutschland GmbH	1
Zhongguo Dianji Gongcheng Xuebao	1
Energies	3
Total	**28**

Figure 5

Bar chart showing the type of publication



It is noteworthy that the primary source appears to be IEEE, with five articles published across its journals and conferences, followed by MDPI, which contributes two articles from the *Energies* journal.

Author Characterization

The examination of authorship reveals a pattern consistent with the observations above. Among the analyzed articles, only one notable instance of prolific authorship is identified: Pilehvar, M.S., and Mirafzal, B. each have three publications, while all other authors contribute only one article each.

This suggests a dichotomy in the authors' engagement with the subject matter—either they are relatively new entrants exploring this research domain, or they have selectively opted to diverge from it for unspecified reasons. The comprehensive list of authors is detailed in Table 3.

Table 3

Relationship between authors and the number of publications

Authors	Articles
Anttila, S.; Döhler, J.S.; Oliveira, J.G.; Boström, C.	1
Arou, A.J.; Tsuji, T.	1
Attou, N.; Zidi, S.-A.; Hadjeri, S.; Khatir, M.	1
Cheng, Z.; Lin, H.; Liang, W.; Zhu, L.; Zheng, Y.	1
Fani, B.; Shahgholian, G.; Haes Alhelou, H.; Siano, P.	1
Hmad, J.; Houari, A.; Bouzid, A.E.M.; Saim, A.; Trabelsi, H.	1
Hsu, C.-T.; Cheng, T.-J.; Huang, H.-M.; Lee, Y.-D.; Chang, Y.-R.; Jiang, J.-L.	1
Hu, C.; Shi, X.; Luo, S.; Zhou, J.; Ma, R.; Fan, H.	1
Ide, T.; Hirase, Y.; Yoshimura, E.; Umezu, Y.; Bando, S.; Sugimoto, K.	2
Jasim, A.M.; Jasim, B.H.	1
Joshal, K.S.; Gupta, N.	1
Khan, S.; Iqubal, N.; Prasad, S.	1
Luo, S.; Peng, K.; Hu, C.; Shi, X.; Lu, H.	1
Matthee, A.; Moonen, N.; Sulaeman, I.; Leferink, F.	1
Pahasa, J.; Potejana, P.; Ngamroo, I.	1
Pilehvar, M.S.; Mirafzal, B.	3
Samanta, S.; Datta, S.; Das, S.; Roy, B.K.; Ganguly, A.	1
Shi, H.; zhang, J.; Zhou, J.; Li, Y.; Jiang, Z.	1
Shi, Y.; Liu, Z.; Liu, J.; Wang, W.; An, R.	1
Singh, S.K.; Rawal, M.; Rawat, M.S.; Gupta, T.N.	1
Sun, G.; Li, Y.; Jin, W.; Gao, Y.	1
Wang, H.; Wang, M.; Cheng, Q.; Lv, S.; Ji, X.	1
Xia, F.; Xia, Z.; Di, Z.; Yang, Z.; Huang, X.; Song, L.	1
Zhang, C.; Xu, J.; Qing, H.; Chai, X.; Wang, X.	1
Zheng, F.; Lin, X.; Lin, Y.; Zhang, Y.; Zhang, Y.	1
Total	**28**

Language Classification

It is essential to acknowledge that the search was conducted exclusively in English, as all identified articles included English versions of their abstracts and keywords. Considering this, Table 4 provides a breakdown of the exclusion criteria, noting that three articles were excluded because they were written in Chinese.

The selection of the final set of articles for this review was guided by a series of inclusion and exclusion criteria designed to ensure thematic relevance, methodological rigor, and accessibility of information. Given the technical nature of the topic, focused specifically on voltage and frequency fluctuation mitigation in inverter-based isolated microgrids, only peer-reviewed journal articles and conference proceedings were considered. These documents were required to provide concrete technical contributions, such as proposed control architectures, stability enhancement techniques, or simulation/experimental validation in isolated or mixed-inertia contexts.

Studies addressing generic smart grid developments, policy frameworks, or grid-connected systems, but not those tackling the challenges specific to islanded operation, were excluded to maintain thematic coherence. In addition, the language filter was intentionally set to English to ensure consistency in terminology and technical interpretation, and to facilitate citation tracking and quality assessment using established bibliometric tools.

Articles for which only the abstract or partial content was accessible were excluded, regardless of relevance, due to the inability to validate methodological details. Furthermore, duplicate entries and documents whose focus was not aligned with the key research questions, such as those emphasizing grid protection, economic optimization, or load forecasting without explicit treatment of dynamic control, were also omitted.

As shown in Table 4, these criteria led to the exclusion of six documents from the refined set of 28 initially identified through keyword mapping with VOSviewer. The remaining 22 articles constitute a curated body of evidence that directly addresses the core objective of this review: evaluating advanced control strategies for voltage and frequency stability in low-inertia, inverter-dominated, and islanded microgrids.

Table 4

Item exclusion report

Art. Num.	Ref.	Title	Reason for exclusion
1	(Sun et al., 2019)	A Comprehensive Power Quality Control Strategy for Microgrid Based on Three-phase Multi-function Inverters	Excluded by language (Chinese)
2	(Attou et al., 2023)	A Control Design of Grid-Forming and Grid-Following Inverters with a Seamless Transition in Microgrid	Not excluded
3	(Y. Shi et al., 2025)	A Decentralized Secondary Voltage Control Method with Unbalance Voltage Compensation Capability for Parallel Inverters in Islanded Microgrids	Not excluded
4	(H. Shi et al., 2021)	A Novel H∞ Robust Control Strategy for Voltage Source Inverter in Microgrid	Not excluded
5	(Hmad et al., 2023)	A Review on Mode Transition Strategies between Grid-Connected and Stand-alone Operation of Voltage Source Inverters-Based Microgrids	Not excluded
6	(Arou & Tsuji, 2024)	Coordinated Q-V/P-f Control Strategy Using Virtual Power Factor for Autonomous AC Microgrid with PV Smart Inverters	Not excluded

Art. Num.	Ref.	Title	Reason for exclusion
7	(Joshal & Gupta, 2023)	Decentralized Control for Multiple Network-Forming Inverters in a Solar PV-BESS Based Stand-alone Microgrid System	Not excluded
8	(Hu et al., 2021)	Decentralized Dynamic Disturbance Compensation Control Strategy for Multiple Parallel Inverters in Microgrid	Excluded by language (Chinese)
9	(Luo et al., 2022)	Decentralized Dynamic Disturbance Compensation Control Strategy for Multiple Parallel Inverters in Microgrid	Exclude due to lack of access
10	(Samanta et al., 2021)	Design and FPGA Implementation of an Islanding Detection cum Re-synchronization Technique for a Grid Connected Inverter in a DC Microgrid	Not excluded
11	(Zheng et al., 2019)	Design of a novel hybrid control strategy for es grid-connected inverter for smooth microgrid transition operation	Not excluded
12	(Pilehvar & Mirafzal, 2020a)	Energy-storage fed smart inverters for mitigation of voltage fluctuations in islanded microgrids	Not excluded
13	(Pilehvar & Mirafzal, 2020b)	Frequency and voltage support by battery-fed smart inverters in mixed-inertia microgrids	Not excluded
14	(Anttila et al., 2022)	Grid Forming Inverters: A Review of the State of the Art of Key Elements for Microgrid Operation	Not excluded
15	(Jasim & Jasim, 2022)	Grid-Forming and Grid-Following Based Microgrid Inverters Control	Not excluded
16	(S. K. Singh et al., 2021)	Hybrid islanding detection technique for inverter based microgrid	Not excluded
17	(Ide et al., 2025a)	Identifying Power Oscillation Factors and Improving Stability in Microgrids Comprised of Inverter-Based Resources	Excluded by language (Japanese)
18	(Fani et al., 2022)	Inverter-based islanded microgrid: A review on technologies and control	Not excluded
19	(Ide et al., 2025b)	Investigating and addressing synchronous instabilities in inverter-based resources within microgrids	Not excluded
20	(Wang et al., 2022)	Modelling simulation and inverter control strategy research of microgrid in grid-connected and island mode	Not excluded
21	(Pahasa et al., 2021)	Multi-objective decentralized model predictive control for inverter air conditioner control of indoor temperature and frequency stabilization in microgrid	Not excluded
22	(Hsu et al., 2019)	Over frequency control of photovoltaic inverters in an island microgrid	Not excluded
23	(Pilehvar & Mirafzal, 2020c)	PV-fed smart inverters for mitigation of voltage and frequency fluctuations in islanded microgrids	Not excluded
24	(Cheng et al., 2022)	Research on Adaptive Control Strategy of Microgrid Inverter based on Virtual Synchronous Generator	Not excluded
25	(Xia et al., 2018)	Resistance capacitive inverter allocation method based on fast reactive support based on Microgrid	Not excluded
26	(Zhang et al., 2022)	Seamless Transferring Control Strategy for Master-Slave Microgrid Inverter in Whole Off-grid Process	Excluded by language (Chinese)
27	(Matthee et al., 2024)	Transient Response of Generator- and Inverter-Based Microgrids to Rapid Load Changes	Not excluded

Art. Num.	Ref.	Title	Reason for exclusion
28	(Khan et al., 2022)	Voltage Regulator Using Sliding Mode Controller for Inverter Based Islanded Microgrid	Excluded due to lack of access

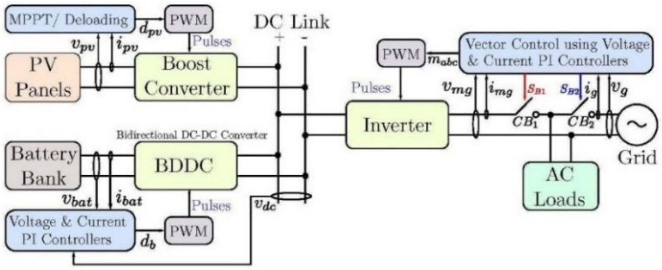
Isolated Microgrids

Microgrids are composed of distributed generation sources, energy storage systems, electrical loads, monitoring devices, and protection devices that can operate in either grid-connected or isolated mode (Wang et al., 2022). Microgrids represent a crucial approach for ensuring the sustainability of electricity supply, particularly in rural areas where extending the main grid is not feasible, or in completely isolated areas such as island territories (Fani et al., 2022; Ide et al., 2025b).

Currently, inverter-based microgrids are gaining prominence because they possess self-healing or islanding capabilities and demonstrate enhanced operational stability (Fani et al., 2022). Two distinct microgrid cases are shown in Figures 6 and 7. Figure 6 shows a grid-connected DC microgrid, while Figure 7 depicts a typical inverter-based microgrid scheme.

Figure 6

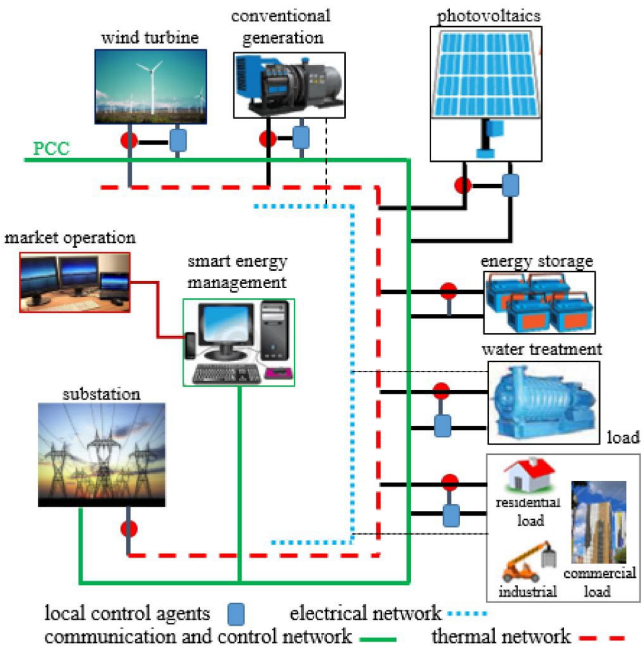
Structure of a DC microgrid connected to the network



Source: control scheme taken from S. Samanta et al., 2021.

Figure 7

Typical schematic of an inverter-based microgrid

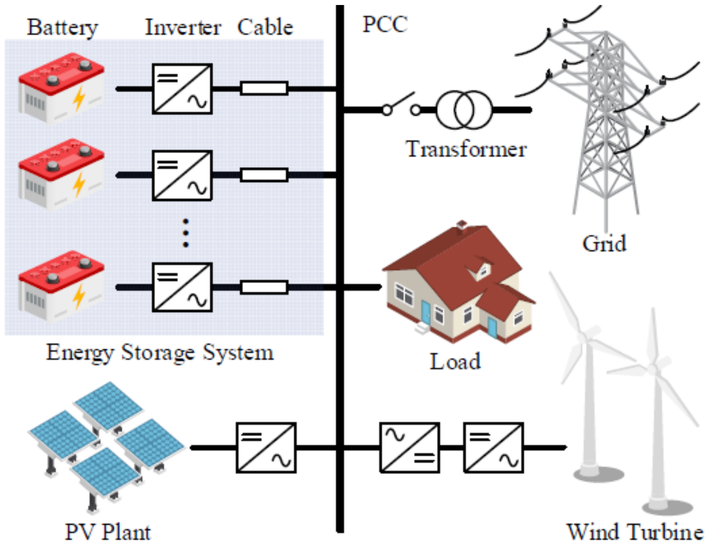


Source: microgrid scheme take from Fani, et al., 2022.

The benefits of microgrids include security of supply, utilization of renewable energy with on-demand storage systems, and reduced operating costs. Additionally, power fluctuations can be mitigated through energy storage (Samanta et al., 2021; H. Shi et al., 2021; Zheng et al., 2019). Figure 8 illustrates a more dynamic microgrid scheme, encompassing all its components—generation, storage, and energy consumption. In microgrids with air-conditioning inverters, regulating power consumption reduces frequency fluctuations.

Figure 8

Microgrid scheme with a parallel inverter system

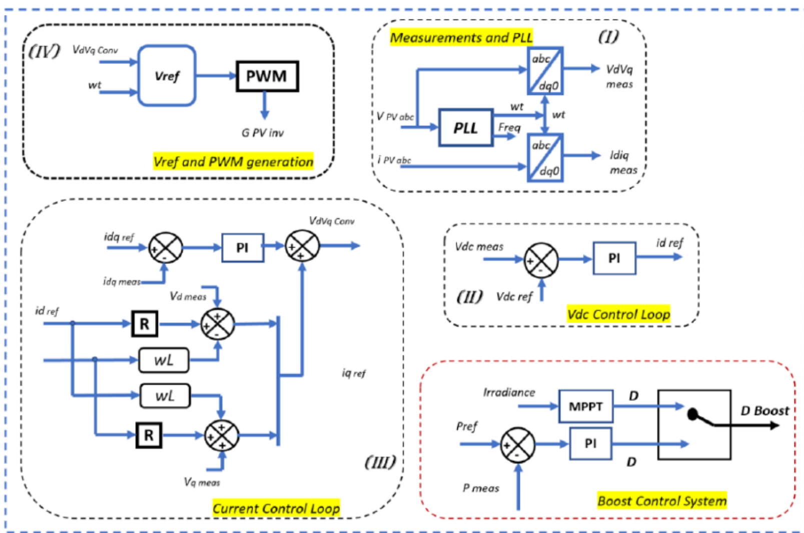


Source: case of study taken from Shi, et al., 2025.

In Hmad et al. (2023), the microgrid is analyzed from a control-system perspective, considering transition strategies between grid-connected and isolated operation modes. Similarly, Attou et al. (2023) present a control scheme for the microgrid under study, which incorporates network formation and monitoring conditions, as illustrated in Figure 9.

Figure 9

Control system of the PV microgrid



Source: microgrid type network formation taken from Attou, et al., 2023.

Mixed Inertia Microgrids

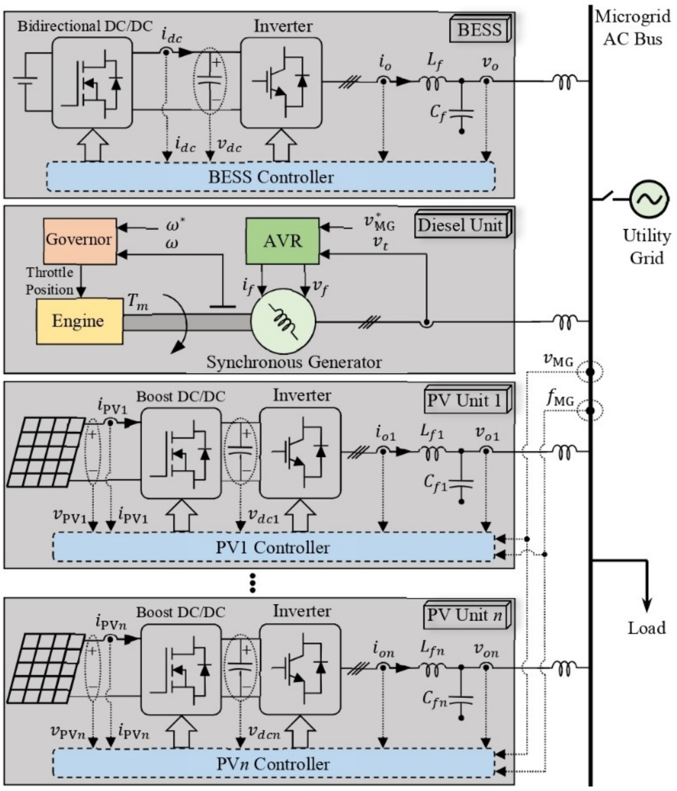
Among the various microgrid configurations, the most used today is the mixed-inertia configuration. This configuration consists of a microgrid generator group that integrates two or more types of energy sources—most frequently diesel generation, often combined with photovoltaic or wind energy (Pilehvar & Mirafzal, 2020a, 2020b, 2020c). However, this type of microgrid presents drawbacks in terms of energy stability due to the low inertia of non-conventional renewable energy sources, leading to an imbalance between generation and consumption (Pilehvar & Mirafzal, 2020a, 2020b). This occurs only in the isolated microgrid operating mode, since in a configuration connected to the main grid, fluctuations are compensated by the public grid AC bus's voltage and frequency regulation (Pilehvar & Mirafzal, 2020a).

Among the most common ways to mitigate these imbalances are the use of diesel generators for voltage and frequency regulation (Pilehvar & Mirafzal, 2020b) and the employment of energy storage systems to inject or absorb reactive power to the grid, thereby improving stability quickly during transients (Pilehvar & Mirafzal, 2020c).

This type of microgrid is illustrated in Figure 10, which shows diesel generation, photovoltaic generation, a grid connection switch, and load.

Figure 10

Schematic of the mixed-inertia microgrid



Source: microgrid scheme consulted in Pilehvar y Mirafzal, 2020c.

Isolation Detection Methods in Microgrids

Isolation detection in microgrids is a significant challenge for ensuring operational stability. These detection methods are generally categorized into local and remote (Anttila et al., 2022).

Local methods, as the name suggests, are physically tied to the microgrid and are further divided into active, passive, and hybrid (Anttila et al., 2022).

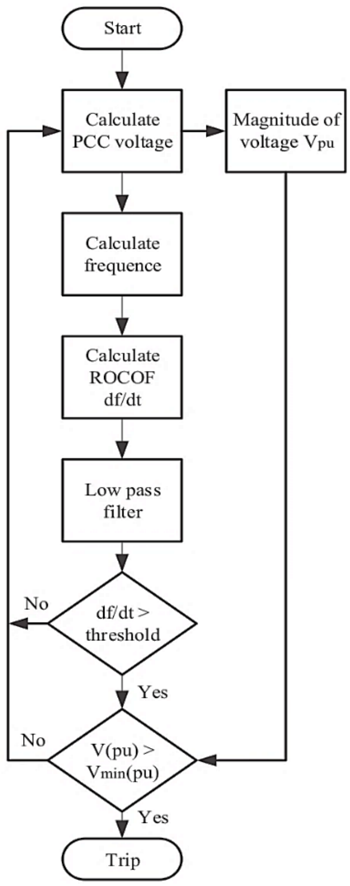
Active methods involve injecting harmonics or disturbances into the grid to detect isolation, thereby reducing isolation detection time and avoiding deterioration of power quality (Samanta et al., 2021). Among the most common active techniques are impedance measurement, active frequency shunt, sliding mode frequency shift, Sandia voltage shift, and Sandia frequency shift (Anttila et al., 2022).

Passive methods rely on measuring parameters such as voltage, current, impedance, power, and frequency (Matthee et al., 2024; Samanta et al., 2021). Their main drawbacks are the isolation detection time and the presence of a non-detection zone (Samanta et al., 2021), although they do not affect power quality (Samanta et al., 2021). Passive methods include ROCOP (rate of change of output power), ROCOF (rate of change of output frequency), and the phase hopping detection method (Anttila et al., 2022).

In S. K. Singh et al. (2021), the passive ROCOF and VU (voltage unbalance) methods are discussed. For the ROCOF method, illustrated in Figure 11, a detection time of 24 ms was obtained. For the VU method detailed in Figure 12, the detection time was 53 ms. The same study also proposes a passive-hybrid method combining the union of ROCOF and VU methods. In this method, the three-phase voltage is controlled in the DG, and VU is calculated. Then, ROCOF determines whether disconnection is required. This approach achieved a detection time of 22 ms and is detailed in Figure 13.

Figure 11

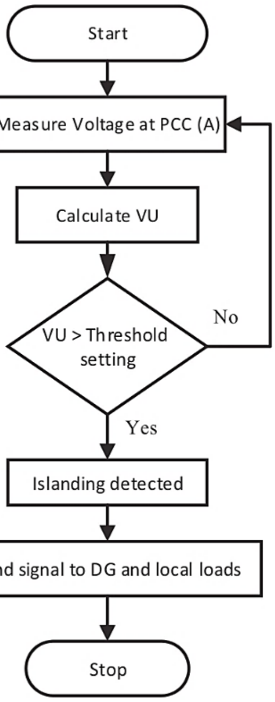
Block diagram of the ROCOF method for isolation detection



Source: ROCOF diagram published in Singh et al., 2021.

Figure 12

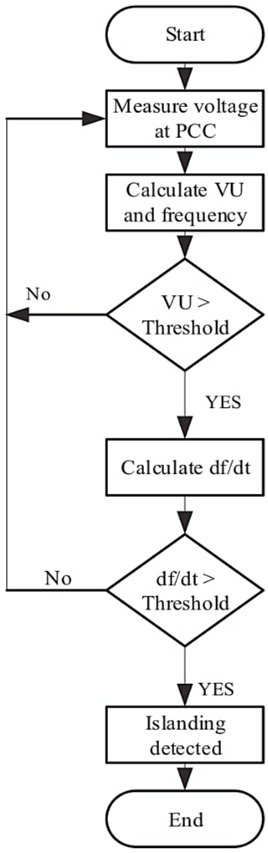
Block diagram of the VU method for isolation detection



Source: block diagram presented in Singh, et al., 2021.

Figure 13

Block diagram of the passive-hybrid method combining ROCOF and VU methods for isolation



Source: block diagram of ROCOF taken from Singh, et al., 2021.

Hybrid methods integrate active and passive approaches to compensate for the limitations of each. For example, the voltage unbalance and frequency set point method combines voltage displacement and reactive power (Anttila et al., 2022).

Unlike local methods, remote methods have their origin in their utility (Anttila et al., 2022) and are based on utility communication, power line carrier communication, supervisory control, and data acquisition techniques (Anttila et al., 2022). Intelligent methods based on decision trees, artificial neural networks, fuzzy logic, support vector machines, etc., are also considered (Samanta et al., 2021).

In this context, the resynchronization of the system during the transition from on-grid to off-grid plays a crucial role, allowing voltage or frequency variations to be minimized using methods such as the MPPT analyzed in Jasim and Jasim (2022).

Control Strategies for the Stability of Isolated Microgrids

In recent years, several control strategies have been developed to mitigate various fluctuations in microgrids, while accounting for challenges such as isolation detection and stability during state changes. Existing control strategies are known to work satisfactorily only for one of the microgrid modes: either connected to the grid or operating in isolation (Wang et al., 2022).

Mitigation Strategies for Voltage Fluctuations in Isolated Microgrids

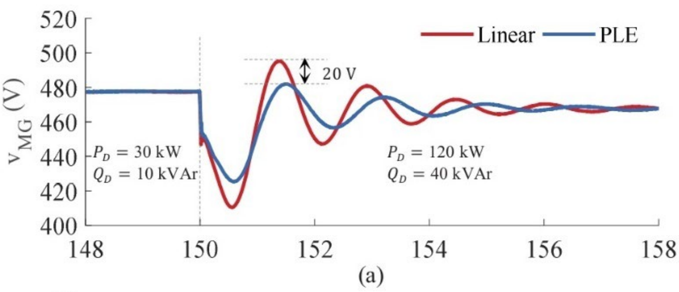
Voltage is one of the most unstable parameters in isolated microgrids, due to typical events that alter system operation.

Among the works reviewed for this literature review, one proposes the H∞ method, which, despite its mathematical complexity, focuses on controlling cross-coupled multivariate systems (H. Shi et al., 2021). It involves adding an adaptive virtual impedance group to mitigate the voltage deviation caused by load variations. This method is applied to the voltage-source inverter and improves power quality (H. Shi et al., 2021).

Pilehvar and Mirafzal (2020a) discuss modifying the conventional control scheme of the battery energy storage system to enhance the dynamic performance of the microgrid. In the BESS, a piecewise linear elliptic droop PLE is employed to improve the voltage profile by injecting/absorbing reactive power during transients. In this method, the BESS becomes a smart inverter. The results of this method are shown in Figure 14.

Figure 14

Comparison of voltage versus system dynamic response for linear and PLE drops at the AC bus



Source: result of voltage published in Pilehvar y Mirafzal, 2020a.

On the other hand, Xia et al. (2018) discuss a fast reactive power support RC inverter method and its parallel power allocation method. It introduces a virtual complex impedance of resistance and capacitance in the inverter output current feedback. This method provides rapid reactive power support at the common connection point, stabilizing the voltage and suppressing resonance between the impedances.

Finally, Luo et al. (2022) propose a dynamic compensation control strategy based on the generator's residual robustness, thereby compensating for voltage variations.

Frequency Variation Mitigation Strategies in Isolated Microgrids

Frequency is another fundamental parameter of microgrids, as it helps to understand the behaviour of electrical signals.

Among the papers considered for this review, two methods were specifically developed to stabilize the frequency in isolated microgrids.

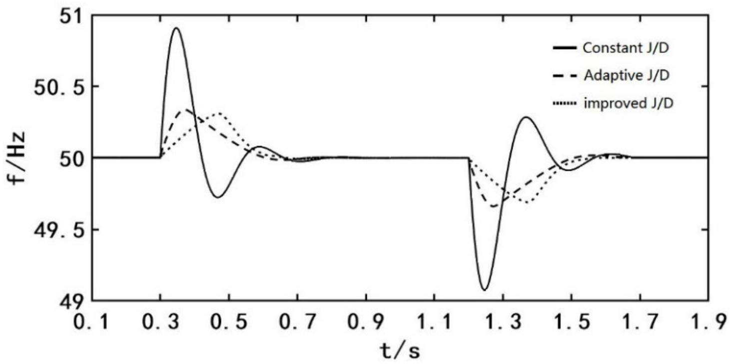
Hsu et al. (2019) analyse the impact of power variation in a photovoltaic power plant on the frequency response of an isolated microgrid with photovoltaic power and diesel thermal generation. A comparison of the response to frequency variation with and without inverter over-frequency compensation is detailed. This method improves the reliability of the microgrid (Hsu et al., 2019).

The method proposed by Cheng et al. (2022), in contrast, adjusts the synchronous virtual generator's frequency using an adaptive droop coefficient that varies with system load, thereby compensating for system frequency fluctuations. Figure 15 shows the frequency response curve with the proposed method.

Finally, Joshal & Gupta (2023) present the PLL (phase-locked loop) method, which involves the connection and disconnection of the DER system during microgrid operation.

Figure 15

Frequency response curve



Source: Results reported by Cheng, et al., 2022.

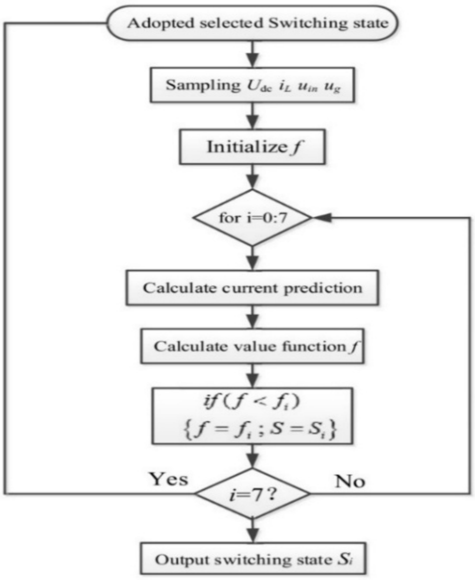
Proposed Strategies to Mitigate Voltage and Frequency Variations Jointly

Among the articles reviewed, four different methods were identified for stabilizing voltage and frequency simultaneously, with the objective of increasing system reliability.

One of the strategies is a hybrid energy storage control strategy based on the IEEE 1676 standard (Zheng et al., 2019). It consists of a predictive controller with a two-degree-of-freedom algorithm and modified droop control, enabling a smooth transition between grid-connected and isolated modes while maintaining the energy storage connection. Its operation is detailed in the diagram in Figure 16. This allows the voltage and frequency to be quickly restored. The results are presented as bar diagrams in Figure 17.

Figure 16

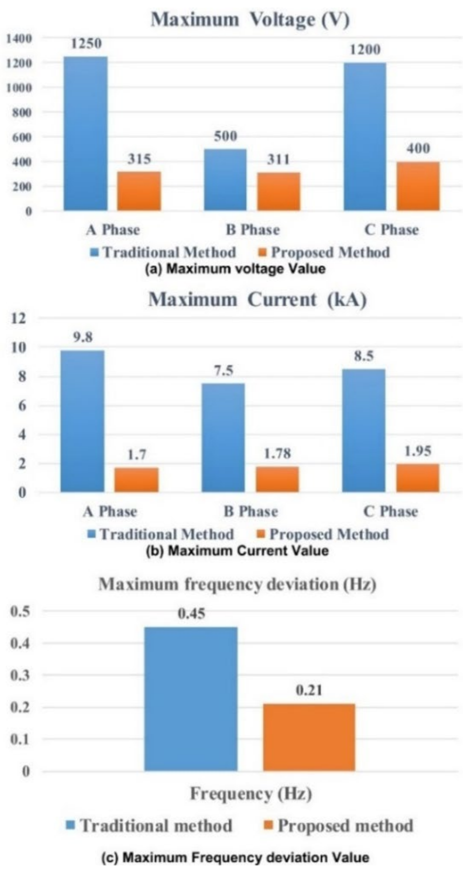
Flow diagram of the predictive controller



Source: control strategy taken from Zheng, et al., 2019.

Figure 17

Performance comparison of the method of control

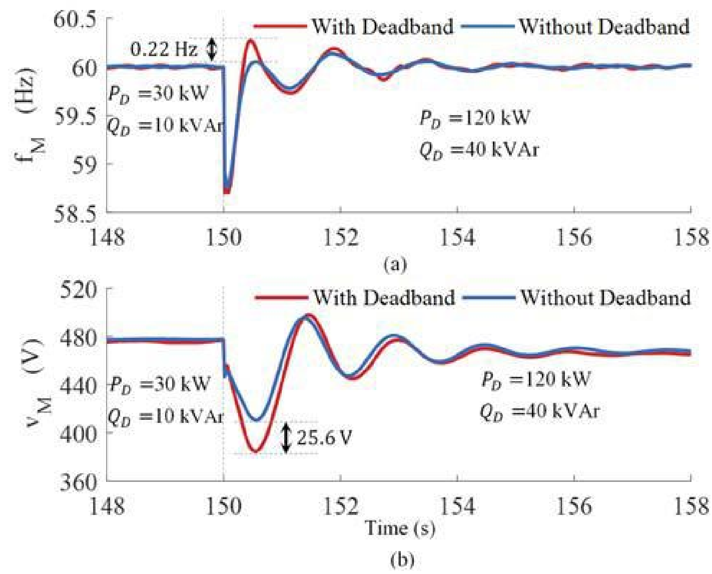


Source: statistics extracted from Zheng, et al., 2019.

The same PLE method, as explained above for voltage stabilization (Pilehvar & Mirafzal, 2020a), is employed in Pilehvar and Mirafzal (2020b), but with an approach that mitigates both frequency and voltage variations simultaneously. In this case, the presence of a deadband in the system is considered, which affects abrupt changes in active power, as shown in Figure 18. The PLE method, applied during staggered variations in load demand, is also analyzed, with the results shown in Figure 19. Finally, the efficiency of the PLE method during the transition between grid-connected and stand-alone mode is examined, as illustrated in Figure 20.

Figure 18

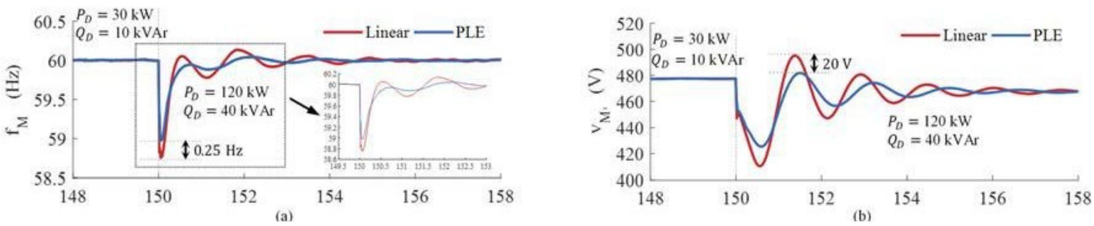
Frequency (a) and voltage (b) variations in the presence and absence of the deadband in linear droop



Source: results published by Pilehvar y Mirafzal, 2022b.

Figure 19

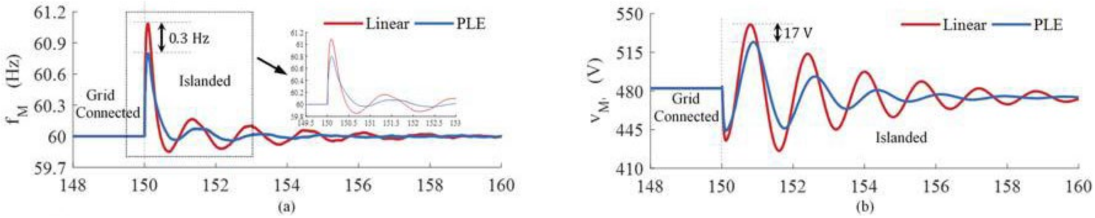
Comparison of linear droop and PLE performance in dynamic response of the system



Source: curves reported by Pilehvar y Mirafzal, 2020b.

Figure 20

Comparison of linear droop and PLE performance in enhanced dynamic response during transients

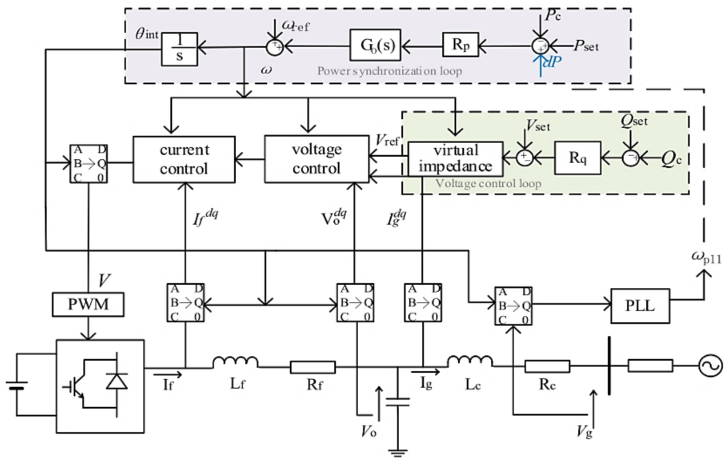


Source: results taken from Pilehvar y Mirafzal, 2020b.

The virtual adaptive control loop method involves modifying the virtual impedance value adaptively based on the output conditions (Wang et al., 2022). In the active power control loop, the frequency signal is extracted from the phase-locked loop and converted into a power feedback variable via a signal transformation, thereby participating in the power control process and enhancing control accuracy. Figure 21 shows the block diagram of the control strategy described. Voltage changes are shown in Figure 22, and frequency changes in Figure 23.

Figure 21

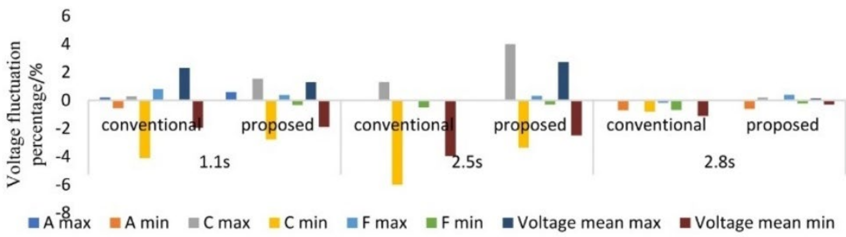
Block diagram of the control strategy proposed



Source: schematic taken from Wang, et al., 2022.

Figure 22

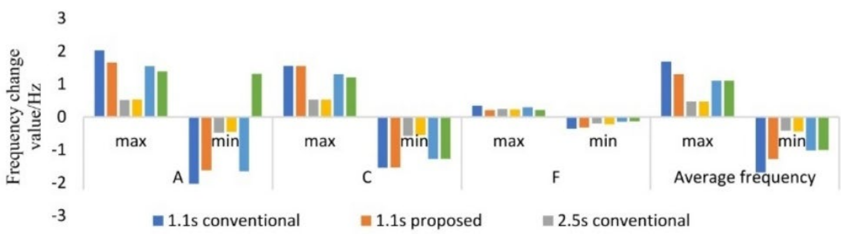
Voltage changes at typical nodes before and after the events explained



Source: results published by Wang, et al., 2022.

Figure 23

Frequency changes at typical nodes, considering the events mentioned

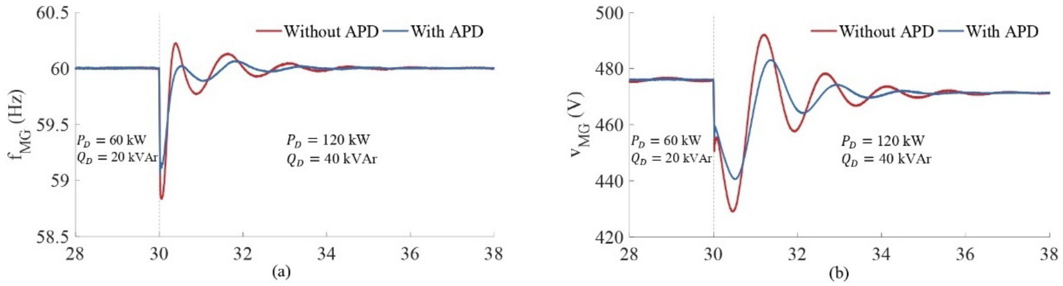


Source: statistics reported by Wang, et al., 2022.

Finally, Pilehvar and Mirafzal (2020c) propose a traditional PV generation controller to improve the dynamics of isolated microgrids by reducing voltage and frequency variations. This method implements a piecewise adaptive droop curve in PV units to achieve faster supply-demand balance during transients. Reactive power is also injected/absorbed to improve voltage and frequency, as in Pilehvar and Mirafzal (2020a). The comparison of curves with and without the APD method is shown in Figure 24.

Figure 24

Frequency (a) and voltage (b) stability curves resulting from the APD method analyzed



Source: curves taken from Pilehvar y Mirafzal, 2020c.

Conclusions

This review examined 28 recent studies addressing voltage and frequency fluctuations in isolated microgrids, with a particular focus on control strategies involving smart inverters, energy storage systems, and advanced regulation techniques. The findings highlight that mixed inertia microgrids—those combining conventional and renewable generation—pose the most significant operational challenges due to the limited inertia of renewable sources. In these contexts, rapid and accurate isolation detection is essential to prevent instability during mode transitions.

Although the reviewed methods demonstrate promising results, they vary considerably in complexity and implementation requirements. Techniques such as adaptive droop control, virtual impedance tuning, and predictive optimization algorithms have shown strong potential to enhance the dynamic performance of low-inertia systems. However, their effectiveness is closely tied to the specific configuration and operating conditions of the microgrid.

The growing number of publications over the last decade underscores the increasing relevance of this research field. Nonetheless, the dispersion of contributions across journals and authors suggests the absence of a consolidated research community or standardized evaluation benchmarks.

This dispersion also points to a lack of consensus on optimal design practices, particularly regarding trade-offs among control complexity, communication requirements, and real-time computational burden. While advanced control schemes often demonstrate superior performance in simulations, their real-world applicability may be constrained by hardware limitations or by the lack of interoperability between devices from different manufacturers. Therefore, future studies should not only assess technical performance but also address scalability, cost-effectiveness, and ease of integration with existing infrastructures.

Furthermore, this review highlights a methodological gap in the comparative evaluation of control strategies, as most studies use different testbeds, metrics, or simulation environments. This limits the generalizability of results and hinders the establishment of standardized benchmarks. Coordinated efforts to develop common microgrid test cases that incorporate representative disturbances, realistic load profiles, and hybrid generation mixes would significantly improve the comparability and replicability of future studies.

From a system design perspective, there is an increasing need to move beyond isolated solutions and explore integrated control layers that combine frequency regulation, voltage support, energy storage coordination, and fault management in a unified framework. Hybrid approaches that synergize predictive, adaptive, and data-driven techniques (such as neural networks or fuzzy logic) may offer enhanced resilience against stochastic events such as sudden load changes or renewable output variability. However, such approaches must be critically evaluated under both normal and abnormal operating conditions to assess their robustness.

Future work should prioritize comparative validation of control strategies under unified test conditions and promote the development of modular, scalable solutions adaptable to diverse microgrid architectures. In addition, there is a need to further explore hybrid approaches that integrate control, storage, and communication layers to improve system resilience in the face of stochastic fluctuations.

Acknowledgements and Declarations

This work was supported by the Laboratorio de Micro-Red, Faculty of Engineering at the Universidad de Cuenca, whose infrastructure and technical resources greatly contributed to the analysis and validation of the findings presented in this study.

According to the CRediT taxonomy, both authors contributed equally to the conception, development, and writing of the manuscript. Their collaboration included defining research objectives, conducting data analysis, interpreting results, and preparing the manuscript.

The authors declare that, in the preparation of this article, artificial intelligence tools (ChatGPT, GPT-5 version) were employed exclusively to improve the linguistic quality and fluency of the English text. All ideas, methodological developments, data interpretation, and scientific conclusions are the original intellectual work of the authors.

References

Anttila, S., Döhler, J. S., Oliveira, J. G., & Boström, C. (2022). Grid Forming Inverters: A Review of the State of the Art of Key Elements for Microgrid Operation. *Energies, 15*(15). https://doi.org/10.3390/en15155517

Arou, A. J., & Tsuji, T. (2024). Coordinated Q-V/P-f Control Strategy Using Virtual Power Factor for Autonomous AC Microgrid with PV Smart Inverters. *IEEJ Transactions on Electrical and Electronic Engineering, 19*(3), 327-341. https://doi.org/10.1002/tee.23980

Attou, N., Zidi, S.-A., Hadjeri, S., & Khatir, M. (2023). A Control Design of Grid-Forming and Grid-Following Inverters with a Seamless Transition in Microgrid. EEA - *Electrotehnica, Electronica, Automatica, 71*(2), 10-18. https://doi.org/10.46904/eea.23.71.2.1108002

Bassey, O., & Butler-Purry, K. L. (2020). Black start restoration of islanded droop-controlled microgrids. *Energies, 13*(22). https://doi.org/10.3390/en13225996

Bassey, O., & Butler-Purry, K. L. (2022). Islanded Microgrid Restoration Studies with Graph-Based Analysis. *Energies, 15*(19). https://doi.org/10.3390/en15196979

Cheng, Z., Lin, H., Liang, W., Zhu, L., & Zheng, Y. (2022). Research on Adaptive Control Strategy of Microgrid Inverter based on Virtual Synchronous Generator. *ACM Int. Conf. Proc. Ser.,* 1027-1031. https://doi.org/10.1145/3558819.3565462

Elmetwaly, A. H., Eldesouky, A. A., & Sallam, A. A. (2020). An Adaptive D-FACTS for Power Quality Enhancement in an Isolated Microgrid. *IEEE Access, 8,* 57923-57942. https://doi.org/10.1109/ACCESS.2020.2981444

Fani, B., Shahgholian, G., Haes Alhelou, H., & Siano, P. (2022*). Inverter-based islanded microgrid: A review on technologies and control. E-Prime - Advances in Electrical Engineering, Electronics and Energy, 2.* https://doi.org/10.1016/j.prime.2022.100068

Hmad, J., Houari, A., Bouzid, A. E. M., Saim, A., & Trabelsi, H. (2023). A Review on Mode Transition Strategies between Grid-Connected and Stand-alone Operation of Voltage Source Inverters-Based Microgrids*. Energies, 16*(13). https://doi.org/10.3390/en16135062

Hsu, C.-T., Cheng, T.-J., Huang, H.-M., Lee, Y.-D., Chang, Y.-R., & Jiang, J.-L. (2019). Over frequency control of photovoltaic inverters in an island microgrid. *Microelectronics Reliability, 92,* 42-54. https://doi.org/10.1016/j.microrel.2018.11.011

Hu, C., Shi, X., Luo, S., Zhou, J., Ma, R., & Fan, H. (2021). Decentralized Dynamic Disturbance Compensation Control Strategy for Multiple Parallel Inverters in *Microgrid. Zhongguo Dianji Gongcheng Xuebao/Proceedings of the Chinese Society of Electrical Engineering, 41*(13), 4425-4438. https://doi.org/10.13334/j.0258-8013.pcsee.201258

Ide, T., Hirase, Y., Yoshimura, E., Umezu, Y., Bando, S., & Sugimoto, K. (2025a). Identifying Power Oscillation Factors and Improving Stability in *Microgrids Comprised of Inverter-Based Resources. IEEJ Transactions on Power and Energy, 145*(3), 299-310. https://doi.org/10.1541/ieejpes.145.299

Ide, T., Hirase, Y., Yoshimura, E., Umezu, Y., Bando, S., & Sugimoto, K. (2025b). Investigating and addressing synchronous instabilities in inverter-based resources within microgrids*. Applied Energy, 377.* https://doi.org/10.1016/j.apenergy.2024.124379

Jasim, A. M., & Jasim, B. H. (2022). Grid-Forming and Grid-Following Based Microgrid Inverters Control. *Iraqi Journal for Electrical and Electronic Engineering, 18*(1), 111-131. https://doi.org/10.37917/ijeee.18.1.13

Joshal, K. S., & Gupta, N. (2023). Decentralized Control for Multiple Network-Forming Inverters in a Solar PV-BESS Based Stand-alone Microgrid System. *Electric Power Components and Systems.* https://doi.org/10.1080/15325008.2023.2283860

Khan, S., Iqubal, N., & Prasad, S. (2022). *Voltage Regulator Using Sliding Mode Controller for Inverter Based Islanded Microgrid.* En Kumar J., Tripathy M., & Jena P. (Eds.), Lect. Notes Electr. Eng. (Vol. 870, pp. 141-152). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-981-19-0193-5_12

Kokila Vani, C., Sarangapani, E., & Kumaresan, R. (2021). *Mitigation of Frequency Variation Through Voltage Control in Islanded Microgrid.* En G. Kumaresan, N. S. Shanmugam, & V. Dhinakaran (Eds.), Advances in Materials Research (Vol. 5, pp. 953-961). Springer Nature Singapore. https://doi.org/10.1007/978-981-15-8319-3_95

Luo, S., Peng, K., Hu, C., Shi, X., & Lu, H. (2022). Decentralized Dynamic Disturbance Compensation Control Strategy for Multiple Parallel Inverters in Microgrid. IEEE Ind. Electron. Soc. Annu. On-Line Conf., ONCON. *1st IEEE Industrial Electronics Society Annual On-Line Conference, ONCON 2022.* https://doi.org/10.1109/ONCON56984.2022.10126896

Matthee, A., Moonen, N., Sulaeman, I., & Leferink, F. (2024). Transient Response of Generator- and Inverter-Based Microgrids to Rapid Load Changes. *IEEE Transactions on Electromagnetic Compatibility, 66*(5), 1646-1654. https://doi.org/10.1109/TEMC.2024.3435732

Mohamed Salim, O., & El-Sayed Salem Aboraya, A. (2024). Power quality enhancement of unbalanced Distributed-Resources based on triple-loop compensation*. Ain Shams Engineering Journal, 15*(2), 102454. https://doi.org/10.1016/j.asej.2023.102454

Ochoa, D., & Martinez, S. (2021). Analytical Approach to Understanding the Effects of Implementing Fast-Frequency Response by Wind Turbines on the Short-Term Operation of Power Systems. *Energies, 14*(12), 3660. https://doi.org/10.3390/en14123660

Pahasa, J., Potejana, P., & Ngamroo, I. (2021). Multi-objective decentralized model predictive control for inverter air conditioner control of indoor temperature and frequency stabilization in microgrid. *Energies, 14*(21). https://doi.org/10.3390/en14216969

Pilehvar, M. S., & Mirafzal, B. (2020a). Energy-storage fed smart inverters for mitigation of voltage fluctuations in islanded microgrids. *IEEE Electr. Power Energy Conf., EPEC. 2020 IEEE Electric Power and Energy Conference, EPEC 2020.* https://doi.org/10.1109/EPEC48502.2020.9319911

Pilehvar, M. S., & Mirafzal, B. (2020b). Frequency and voltage supports by battery-fed smart inverters in mixed-inertia microgrids. *Electronics (Switzerland), 9*(11), 1-14. https://doi.org/10.3390/electronics9111755

Pilehvar, M. S., & Mirafzal, B. (2020c). PV-fed smart inverters for mitigation of voltage and frequency fluctuations in islanded microgrids. *Proc. - Int. Conf. Smart Grids Energy Syst., SGES, 807-812.* https://doi.org/10.1109/SGES51519.2020.00149

PRISMA-P Group, Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews, 4*(1), 1. https://doi.org/10.1186/2046-4053-4-1

Samanta, S., Datta, S., Das, S., Roy, B. K., & Ganguly, A. (2021). Design and FPGA Implementation of an Islanding Detection cum Re-synchronisation Technique for a Grid Connected Inverter in a DC Microgrid. *Int. Conf. Energy, Power Environ.: Towards Clean Energy Technol., ICEPE. 3rd International Conference on Energy, Power and Environment: Towards Clean Energy Technologies, ICEPE 2020.* https://doi.org/10.1109/ICEPE50861.2021.9404503

Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L. A., & the PRISMA-P Group. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015*: Elaboration and explanation. BMJ, 349(jan02 1),* g7647-g7647. https://doi.org/10.1136/bmj.g7647

Shi, H., zhang, J., Zhou, J., Li, Y., & Jiang, Z. (2021). A Novel H∞ Robust Control Strategy for Voltage Source Inverter in Microgrid. Frontiers in *Energy Research, 9.* https://doi.org/10.3389/fenrg.2021.731432

Shi, Y., Liu, Z., Liu, J., Wang, W., & An, R. (2025). A Decentralized Secondary Voltage Control Method with Unbalance Voltage Compensation Capability for Parallel Inverters in Islanded Microgrids. *IEEE Transactions on Power Electronics.* https://doi.org/10.1109/TPEL.2025.3556302

Singh, A. R., Ray, P., Seshu Kumar, R., & Salkuti, S. R. (2023). *Introduction to Power Quality in Microgrids.* En S. R. Salkuti, P. Ray, & A. R. Singh (Eds.), Power Quality in Microgrids: Issues, Challenges and Mitigation Techniques (Vol. 1039, pp. 1-21). Springer Nature Singapore. https://doi.org/10.1007/978-981-99-2066-2_1

Singh, S. K., Rawal, M., Rawat, M. S., & Gupta, T. N. (2021). Hybrid islanding detection technique for inverter based microgrid. *Int. Conf. Emerg. Technol., INCET. 2021 2nd International Conference for Emerging Technology, INCET 2021.* https://doi.org/10.1109/INCET51464.2021.9456307

Sun, G., Li, Y., Jin, W., & Gao, Y. (2019). A Comprehensive Power Quality Control Strategy for Microgrid Based on Three-phase Multi-function Inverters. *Dianwang Jishu/Power System Technology, 43*(4), 1211-1219. https://doi.org/10.13335/j.1000-3673.pst.2018.1765

VOSviewer—Visualizing scientific landscapes. (s. f.). VOSviewer. Last access: July 5th, 2023 from https://www.vosviewer.com/

Wang, H., Wang, M., Cheng, Q., Lv, S., & Ji, X. (2022). Modelling simulation and inverter control strategy research of microgrid in grid-connected and island mode. *Energy Reports, 8,* 206-218. https://doi.org/10.1016/j.egyr.2022.09.117

Xia, F., Xia, Z., Di, Z., Yang, Z., Huang, X., & Song, L. (2018). Resistance capacitive inverter allocation method based on fast reactive support based on Microgrid. *IOP Conf. Ser. Earth Environ. Sci., 170*(4). https://doi.org/10.1088/1755-1315/170/4/042149

Yuan, C., Xie, P., Yang, D., & Xiao, X. (2018). Transient stability analysis of islanded AC microgrids with a significant share of virtual synchronous generators. *Energies, 11(1).* https://doi.org/10.3390/en11010044

Zhang, C., Xu, J., Qing, H., Chai, X., & Wang, X. (2022). Seamless Transferring Control Strategy for Master-Slave Microgrid Inverter in Whole Off-grid Process. *Dianli Xitong Zidonghua/Automation of Electric Power Systems, 46*(23), 125-133. https://doi.org/10.7500/AEPS20210914002

Zheng, F., Lin, X., Lin, Y., Zhang, Y., & Zhang, Y. (2019). Design of a novel hybrid control strategy for es grid-connected inverter for smooth microgrid transition operation. *IEEE Access, 7, 1*71950-171965. https://doi.org/10.1109/ACCESS.2019.2955713